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RESEARCH ARTICLE

Factors Influencing Student STEM Learning: Self-Efficacy and Outcome Expectancy, 21st Century Skills, and Career Awareness

Jung Han[1] · Todd Kelley[1] · J. Geoff Knowles[2]

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Abstract
Social, motivational, and instructional factors impact students' outcomes in STEM learning and their career paths. Based on prior research and expectancy-value theory, the study further explored how multiple factors affect students in the context of integrated STEM learning. High school STEM teachers participated in summer professional development and taught integrated STEM to students during the following school year, where scientific inquiry, biomimicry, 3D printing technology, and engineering design were integrated as instructional strategies. Surveys were conducted to measure teacher self-efficacy and outcome expectancy. Student STEM attitudes (self-efficacy and expectancy-value beliefs), 21st century skills, STEM career awareness, and STEM knowledge achievement were also measured using a survey and a custom-made knowledge test. Based on expectancy-value theory and literature, a path model was developed and tested to investigate causal relationships between these factors. The results revealed direct and indirect effects of teacher self-efficacy and outcome expectancy on students' STEM knowledge achievements. Student STEM attitudes (self-efficacy and expectancy-value beliefs), 21st century skills, and STEM career awareness also significantly influenced STEM knowledge achievement directly or indirectly.

Keywords Integrated STEM education · Self-efficacy · STEM attitude · 21st century skill · STEM career awareness

✉ Todd Kelley
trkelley@purdue.edu

Jung Han
han336@purdue.edu

J. Geoff Knowles
jknowles5@ivytech.edu

[1] Department of Technology Leadership Innovation, Purdue University, Lafayette, IN, USA

[2] Ivy Tech Community College, Lafayette, IN, USA

Introduction

The national efforts for advancing science, technology, engineering, and mathematics (STEM) education is becoming stronger as our society demands a global STEM workforce (Asunda, 2012; Keirl, 2006; Kelley & Knowles, 2016; Li et al., 2019). To help students enhance their achievements in STEM learning, teachers and educators should create appropriate instructional and social learning contexts and develop strategies that positively influence student learning. For this purpose, understanding factors that influence student STEM learning is imperative.

Social, motivational, and instructional factors greatly influence students' achievements in STEM learning and their future careers. (Ketenci et al., 2020; Nugent et al., 2015; Wilson et al., 2015; Zeldin et al., 2008). Prior studies found that students' academic achievements can be impacted by domain-specific self-efficacy, attitudes, and motivation (Pajares & Graham, 1999; Simon et al., 2014; Wiebe et al., 2018; Witt-Rose, 2003). However, although many studies have investigated the relationships between students' self-efficacy, motivation, and learning outcomes, few studies were reported on the multiple factors influencing student learning in STEM. In addition, studies in this area typically have been conducted on a single STEM discipline, especially science and mathematics (Wiebe et al., 2018). Furthermore, research on how self-efficacy and outcome expectancy of both teachers and students collectively affect student learning outcomes is limited. Therefore, the current study examined multiple factors influencing student STEM learning, which include teacher self-efficacy and outcome expectancy, student STEM attitudes (self-efficacy and expectancy-value beliefs), 21st century skills, and STEM career awareness.

We used expectancy-value theory as a framework to hypothesize the path model. Findings will show the direct and indirect effects of multiple factors on student achievement in the integrated STEM teaching and learning context.

Theoretical framework

The current study is guided by expectancy-value theory (Eccles & Wigfield, 2002). Expectancy-value theory has been widely used to explain student performance (Berland & Steingut, 2016; Jackson et al., 2019; Jones et al., 2010). According to Eccles and Wigfield (2002), "expectancies refer to beliefs about how one will do on different tasks or activities, and values have to do with incentives or reasons for doing the activity" (p. 110). These expectancies and values are related to individual's achievement, persistence, and choices in academic tasks (Atkinson, 1964; Eccles & Wigfield, 2002). Therefore, people who have strong beliefs about their competencies of success and efficacy tend to perform better and work on more challenging tasks (Bandura, 1994; Eccles & Wigfield, 2002).

Wiebe et al. (2018) stated that "expectancy-value theory helps frame both self-efficacy in terms of expectancies of success in a particular academic domain and outcome expectancy in terms of the value of this academic subject area to future goals" (p. 2). Bandura differentiated between efficacy expectation (*beliefs about what they can do*) and outcome expectation (*beliefs about the likely outcomes of performance*) and noted that both expectations are closely linked to academic outcomes (Trautwein et al., 2012). Previous research also revealed a significant relationship between expectancy-value beliefs and academic achievements (Bradley et al., 1999; Caraway et al., 2003; Nugent et al., 2015; Pajares & Miller, 1994; Yoon et al., 2012; Wood & Locke, 1987; Zimmerman et al., 1992). Moreover, many studies found “a dynamic, reciprocal nature of self-efficacy, expectancy outcomes, and academic career goals” (Wiebe et al., 2018, p. 2). Specifically, Wiebe et al. (2018) examined the relationships between student attitudes (self-efficacy and expectancy-value beliefs) toward all core STEM subjects and their interests in future STEM careers using the S-STEM survey (Unfried et al., 2015) and found that student attitudes (expectancy-value beliefs) and their career interests are positively associated.

Teacher self-efficacy also has been emphasized as a strong predictor of student outcome and academic achievement (Nadelson et al., 2012; Ross, 1992; Tschannen-Moran & Barr, 2004; Yoon et al., 2012). Teachers' beliefs in their abilities to teach and motivate influence “the types of learning environments they create and the level of academic progress their students achieve” (Bandura, 1993, p. 117), which in turn, significantly influence student STEM interests in future STEM careers (Autenrieth et al., 2018; Brophy et al., 2008; Kelley et al., 2020).

Based on expectancy-value theory and previous research findings, the present study created a hypothesized path model that displays the influence of teacher self-efficacy and outcome expectancy on student STEM attitudes, 21st century skills, STEM career awareness, and STEM knowledge achievement. The results will show the relationship between these factors and the effects of teacher self-efficacy and outcome expectancy on student learning in integrated STEM.

Literature review

Self-efficacy and outcome expectancy

Teachers’ self-efficacy can be defined as “teachers’ personal beliefs in their abilities to positively affect students for educational attainments” (Yoon et al., 2012, p. 26). Prior studies provided empirical evidence that teachers’ beliefs in their teaching efficacy and successful outcome influence students’ self-efficacy, motivation, and performance (Cannon & Scharmann, 1996; Ross et al., 2001; Rutherford et al., 2017). Specifically, research on the relationship between teacher self-efficacy and student outcome in science learning (Bal-Taştan et al., 2018; Salgado et al., 2018) and mathematics learning (Borko & Whitcomb, 2008; Gulistan & Hussain, 2017; Perera & John, 2020) revealed that teachers’ self-efficacy and expectations significantly impact students’ academic achievement. According to researchers, teacher self-efficacy for successful teaching relates to content knowledge, quality pedagogy, and teaching strategies considerably (Knowles, 2017, p. 25; Rutherford et al., 2017; Stohlmann et al., 2012; Yoon et al., 2012).

Students’ confidence in their abilities and perceptions of subjective values are also critical factors that influence their performances (Akey, 2006; Wigfield & Eccles, 2000). Many studies proved the positive association between student self-efficacy and academic success (Henson, 2001; Pajares, 1996; Reyes, 2010). Studies also found that student self-efficacy and expectancy-value beliefs significantly impact their career development and career choices (Ketenci et al., 2020; Lent et al., 2010; Zeldin et al., 2008). Unfried et al. (2015) used the term *attitudes* to indicate both self-efficacy and expectancy-value beliefs. They noted that students' attitudes toward STEM content, as well as their interests in STEM careers and their 21st century skills, can predict student participation in STEM-related careers. The present study also uses the term *attitudes* to indicate student self-efficacy in learning STEM content and their expectancy-value beliefs (Unfried et al., 2015; Wiebe et al., 2018).

21st century skills

Increasing 21st century skills through STEM education has been focused among educators (Bybee, 2010; Jang, 2016; Li et al., 2019). 21st century skills, which include critical thinking, collaboration, creativity, and communication, are necessary skills in the future (International Technology and Engineering Educators Association [ITEEA], 2020; Partnership for 21st Century Skills [P21] n.d.). Li et al. (2019) posited that students can develop thinking skills in a new way in STEM education and that these new thinking skills are connected to 21st century skills.

21st century skills range from individual skills to workforce and social skills, which include skills in life and career, media and information, technology, and so on. (Kelley et al., 2019). Specifically, National Academy of Engineering (NAE and NRC, 2009) proposed engineering habits of mind as essential skills in the 21st century, which include systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations. Similarly, ITEEA (2020) proposed eight technology and engineering practices adopted from 21st century skills (Partnership for 21st Century Skills [P21], n.d.) and engineering habits of mind, which include: 1) Systems thinking; 2) Creativity; 3) Making and Doing; 4) Critical thinking; 5) Optimism; 6) Collaboration; 7) Communication; 8) Attention to Ethics.

Contemporary educational standards indicate that students can enhance 21st century skills and develop confidence through the integration of STEM subjects in project-based instruction. Accordingly, teachers are required to integrate science and engineering practices in their classrooms explicitly for the students to practice real-world problem-solving and increase 21st century skills (Kelley et al., 2020; NGSS Lead States, 2013; NRC, 2012).

STEM career awareness

The term *career awareness* implies "one's own talents and interests or understanding the opportunities and requirements of various career fields" (Braverman et al., 2002, p. 55). There have been growing efforts to advance STEM education to increase students' awareness of STEM careers as our society demands a competent STEM workforce (Kier et al., 2014; NGSS Lead States, 2013). Researchers claim that experiences of STEM practice through STEM education increase students' interests in STEM-related careers and prepare them for future STEM job opportunities (Li et al., 2019; Zuo et al., 2020). Especially, as secondary school years are a critical period for students to decide their future careers, high school STEM teachers need to foster students' STEM career awareness and job interest (Cohen et al., 2013).

STEM career-related instruction facilitates students' interests in STEM learning and helps them be engaged in their learning activities (Salonen et al., 2018). To increase STEM career awareness, teachers are recommended to incorporate teaching strategies that students can research and solve real-world problems as scientists and engineers do. In doing so, students can enhance their understanding of the role of STEM in our society (Cohen et al., 2013; NGSS Lead States, 2013). Particularly, the Next Generation Science Standards (NGSS) present eight science and engineering practices, where students can experience what professional scientists and engineers do. The major practices of science and engineering suggested by the NGSS include: (1) Asking questions and defining problems; (2) Developing and using models; (3) Planning and carrying out investigations; (4) Analyzing and interpreting data; (5) Using mathematics and computational thinking; (6) Constructing explanations and designing solutions; (7) Engaging in argument from evidence; (8) Obtaining, evaluating, and communicating information (NGSS Lead States, 2013). By engaging in these science and engineering practices, students can acquire skills and knowledge needed for postsecondary careers, including the STEM field (NGSS Lead States, 2013).

The present study

The primary goal of the present study is to identify the factors influencing student STEM learning and determine if teacher self-efficacy and outcome expectancy beliefs affect student attitudes (self-efficacy and expectancy-value beliefs) and academic achievements in integrated STEM. A hypothesized path model was developed based on expectancy-value theory and previous research findings (see Fig. 1). The study was guided by two research questions:

1. Are teacher self-efficacy and outcome expectancy, student STEM attitudes, 21st century skills, and STEM career awareness positively associated with student STEM knowledge achievement?
2. Are there any direct and indirect effects of teacher self-efficacy and outcome expectancy on students' STEM attitudes, 21st century skills, and STEM career awareness?

Method

Context of the study

The present study was conducted within an integrated STEM project named *Teachers and Researchers Advancing Integrated Lessons in STEM (TRAILS)*. TRAILS was a three-year-long project funded by the National Science Foundation (Award #DRL-1513248). Researchers, educators, and industry partners cooperated to develop an integrated STEM project and supported high school STEM teachers and their students through a community of practice during the 2016–2019 school years.

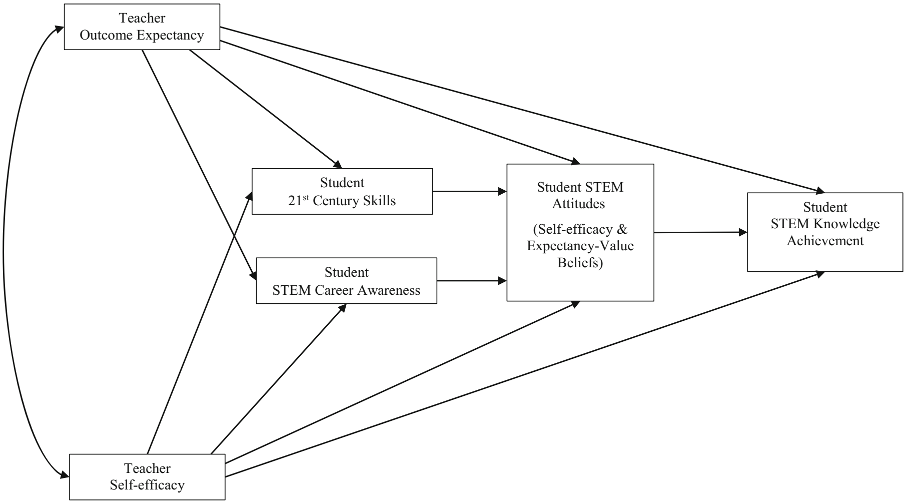

Fig. 1 Conceptual model representing the influence of teacher self-efficacy and outcome-expectancy on students' learning in STEM

The TRAILS project consisted of three cohorts: Cohort 1 was the 2016–2017 school year, Cohort 2 was the 2017–2018 school year, and Cohort 3 was the 2018–2019 school year. Cohort 1–3 high school science teachers and engineering and technology education (ETE) teachers experienced the process of integrating science, technology, engineering, and mathematics into authentic contexts through TRAILS professional development. The participating teachers were selected among the applicants following the criteria: (1) The teachers are required to be high school biology or physics teachers or engineering and technology education (ETE) teachers; (2) The teachers are required to be able to participate in the summer professional development (PD).

A total of 30 STEM teachers (15 science teachers, 15 ETE teachers) were participated in the summer professional development (PD) for two weeks during summer vacation. During the PD, teachers were introduced to an exemplar lesson developed by the research team and learned the lesson from the student's standpoint. The exemplar lesson, which was named *Designing Bugs and Innovative Technology (D-BAIT)*, employed biomimicry concepts for designing the fishing lure that mimics the functions of aquatic insects. The teachers also cogenerated their own integrated lessons as a science and engineering technology teacher pair. During the following year, the teachers taught both exemplar lesson *D-BAIT* and the custom lesson each teacher pair developed in their classrooms.

The *D-BAIT* unit consists of 10–12 sessions including: (1) entomology introductory lesson; (2) entomology field observation and collection of aquatic insects specimens; (3) analysis of the observed data using scientific inquiry and research on aquatic entomology taxonomy and food webs; (4) introduction to design and engineering design process; (5) introduction to CAD software and 3D printing; (6) design of a fishing lure using the biomimicry concept and mathematical modeling of a prototype (buoyancy concept); (7) testing and redesigning the prototype; and 8) evaluation of prototype lures (Han et al., 2020, p. 27).

Data collection

The teachers completed the T-STEM survey, which consists of seven subscales including *teaching self-efficacy toward educating STEM content* and *outcome expectancy*, before and after the summer professional development. The survey scores of teachers increased after the summer PD (Kelley et al., 2020), and with the increased teaching efficacy and expectancy beliefs, they taught students during the following school year. Therefore, to see how teacher efficacy and expectancy affect student learning, we used the posttest scores (teacher scores at the point in time of teaching their students) from the T-STEM survey.

Student data were collected from high school science and ETE (engineering and technology education) students in the state of Indiana, who were enrolled in the 2016–2019 school years and experienced integrated STEM lessons from the TRAILS teachers. Students also took the S-STEM survey, which was developed to measure students' attitudes toward STEM, 21st century skills, and STEM career interest, and the *D-BAIT* STEM knowledge test two times respectively before and after they experienced integrated STEM lessons. As the S-STEM post-survey scores and the *D-BAIT* STEM knowledge posttest scores reflect student scores after they learned the *D-BAIT* lesson, these scores were used as student scores for the analysis.

All the surveys were done through the Qualtrics online survey system, and the Institutional Research Board (IRB) approval was obtained in advance.

Final data from the students, who submitted the IRB consent forms from both parents and themselves, are shown in Table 1.

For the current study, a total of 507 data, which do not include missing data, were used for the analysis.

Instrument

S-STEM survey

Friday Institute for Educational Innovation (2012b) developed Student Attitudes toward STEM (S-STEM) survey for Elementary level and Middle/High School level. The present study used the S-STEM survey for Middle/High School Student level to measure high school students' STEM attitudes. The S-STEM survey contains six survey sections. The first three sections ask the students about their attitudes toward math, science, engineering and technology, respectively. The fourth section measures students' 21st century skills (21st century learning confidence). The items in the next section ask students about their interests in STEM jobs and their attitudes toward 12 different STEM career areas. The survey items in the first four subscales ask respondents to report their levels of agreement on a five-point Likert-type scale ranging from "strongly disagree" to "strongly agree". For the items in the fifth subscale, students are asked to rate on a four-point Likert-type scale with 1 being "Not at all interested," 2 "Not so interested," 3 "Interested," and 4 being "Very interested". While developing the S-STEM survey, Cronbach's alpha was used to measure internal-consistency reliability for each of the subconstructs. The first four constructs (math attitudes, science attitudes, engineering and technology attitudes, and 21st century skills) satisfied sufficient levels of reliability, 0.83–0.92, for both Elementary level

Table 1 Final student data collection (2016–2019)

Gender		Ethnicity						Grade					Sum
Male	Female	White	Black	Hispanic	Asian	Multi	Others	8	9	10	11	12	
605 (62%)	373 (38%)	822 (84%)	32 (3%)	78 (8%)	31 (3%)	11 (1%)	4 (0%)	6 (1%)	270 (28%)	206 (21%)	278 (28%)	218 (22%)	978 (100%)

and secondary level surveys (Unfried et al., 2015). Cronbach's alpha for the fifth subscale, interests in STEM jobs, was not reported (Friday Institute for Educational Innovation, 2012b). The items in the sixth survey section were not used for the present study. Table 2 summarizes the S-STEM survey.

STEM knowledge test

To measure the STEM knowledge of the students, the *D-BAIT* knowledge assessment was used. The *D-BAIT* knowledge test was developed by the TRAILS research team to evaluate students' STEM knowledge before and after *D-BAIT*. The *D-BAIT* knowledge test consists of 20 items within three subject domains: engineering design, physics, and biology. The full score of the STEM knowledge test was 20.

The initial *D-BAIT* STEM knowledge test was drafted by a panel of six members including an entomology professor, a biology education professor, an engineering technology teacher educator, a two-year technical college faculty, an entomology major graduate student, and a technology major graduate student. The content and face validity of the instrument were checked by two high school biology and engineering technology teachers, who had more than 15 years of teaching experience. Then the instrument was pilot tested with 429 high school students from 18 STEM classrooms. With the results, item analysis was conducted, and the final version of the *D-BAIT* knowledge test with 20 items was obtained after four items were removed (see Appendix). After removing four items, the overall Cronbach's Alpha score of the final version of *D-BAIT* STEM knowledge test was over .70. The reliability score was also calculated using the adjusted Spearman-Brown prophecy formula (Brown, 1910; Spearman, 1910), and the score was 0.876.

Table 2 S-STEM survey summary (Friday Institute for Educational Innovation, 2012b)

Variables in the present study	S-STEM survey section	Measurement application
STEM attitudes (Self-efficacy & Outcome Expectancy)	Math attitudes	Attitudes toward math – consists of items measuring self-efficacy related to math and expectations for future value gained from success in math
	Science attitudes	Attitudes toward science – consists of items measuring self-efficacy related to science and expectations for future value gained from success in science
	Engineering and technology attitudes	Attitudes toward engineering and technology – consists of items measuring self-efficacy related to engineering and technology and expectations for future value gained from success in engineering and technology
21st century skills	21st century learning	Attitudes toward 21st century learning – consists of items measuring students' confidence in communication, collaboration, and self-directed learning
Career awareness	Your future	Interest in 12 broad categories of STEM career fields
Not used	More about you	

T-STEM survey

For the measures of teacher self-efficacy and teaching outcome expectancy, the T-STEM Survey for technology (ETE) and science teachers was used (The Friday Institute for Educational Innovation, 2012a). According to the survey developer, they adopted the existing survey, Science Teaching Efficacy Belief Instrument (STEBI) (Enochs & Riggs, 1990), for the Personal Teaching Efficacy and Beliefs (PTEB) construct and the Teaching Outcome Expectancy Beliefs (TOEB) construct. The T-STEM Survey consists of 7 subscales including: (1) teaching self-efficacy toward teaching STEM content (PTEB); (2) teacher's expectancy on student learning outcome through effective teaching (TOEB); (3) technology use by students; (4) use of STEM instructional practices, (5) teacher attitudes toward 21st century skills; (6) Teacher leadership attitudes; and (7) STEM career awareness (see Table 3).

For the construct reliability, developers calculated Cronbach's alpha. For the science domain, Cronbach's alpha for teaching efficacy and outcome expectancy were reported to be .908 and .814, respectively. However, the technology domain Cronbach alpha scores for both self-efficacy and outcome expectancy were not reported (Friday Institute for Educational Innovation T-STEM Survey, 2012a). Therefore, we calculated Cronbach's alpha for technology domains with our data, and the results were the following: technology teacher teaching efficacy = .915, technology teacher outcome expectancy = .800.

The survey items used a Likert-type scale with 1 being "Strongly Disagree," 2 "Disagree," 3 "Neither Agree Nor Disagree," 4 "Disagree," and 5 being "Strong Agree" (The Friday Institute for Educational Innovation, 2012a). Table 3 demonstrates the summary of the T-STEM Survey.

Table 3 T-STEM survey summary: T-STEM science and T-STEM technology (Friday Institute for Educational Innovation, 2012a)

Construct	Measurement application
*Personal Teaching Efficacy and Beliefs (Self-efficacy)	Self-efficacy and confidence related to teaching the specific STEM subject
*Teaching Outcome Expectancy Beliefs (Outcome Expectancy)	Degree to which the respondent believes, in general, student-learning in the specific STEM subject can be impacted by actions of teachers Belief in the extent to which effective teaching affects student learning in science or technology (Teaching Outcome Expectancy)
Student technology use	How often students use technology in the respondent's classes
STEM instruction	How often the respondent uses certain STEM instructional practices
21st century learning attitudes	Attitudes toward 21st century learning
Teacher leadership attitudes	Attitudes toward teacher leadership activities
STEM career awareness	Awareness of STEM careers and where to find resources for further information

Note: * used in the present study

Data analysis process

The first subscale, *Teacher Self-efficacy*, in the T-STEM survey consists of 11 Likert-style items, and the second subscale, *Teaching Outcome Expectancy Beliefs*, consists of 9 Likert-style items. All items ranged from 1 (Strongly Disagree) to 5 (Strongly Agree) points. The S-STEM survey for students consists of 49 Likert-style items with five subconstructs: math attitudes, science attitudes, engineering and technology attitudes, 21^{st} century skills, and STEM career awareness of their future. Each item's score in the first four subconstructs ranged from 1(Strongly Disagree) to 5 (Strongly Agree). The items in the fifth subconstruct (career awareness) ranged from 1 (Not at all Interest) to 4 (Very Interest) points (The Friday Institute for Educational Innovation, 2012b).

For each teacher's T-STEM score and student's S-STEM survey subscale scores, the researchers added the values across the questions for each respondent and treated the summed score as each individual's score. As the context of the present study was integrated STEM, and the students experienced integrated STEM teaching and learning, score sums of math attitudes, science attitudes, and technology attitudes in the S-STEM survey were combined to be used as student STEM attitudes score. Each student's ratings on the 21^{st} century skills items and career awareness items - subscales in the S-STEM survey- were summed to be used as student 21^{st} century skills score and STEM career awareness score, respectively. Each teacher's ratings on the self-efficacy questionnaire, the first subconstruct in the T-STEM survey, and Teaching Outcome Expectancy Beliefs, the second subconstruct in the T-STEM survey, were also summed to be used as teacher scores (Teacher Self-efficacy & Outcome Expectancy).

Some scores (responses to the negative statements) were reversed in advance, and teacher scores were matched to their students. Table 4 shows all the variables and the full scores.

Data analysis method

Path analysis is known to be a useful method for identifying relationships among a set of variables as the structural model (path diagram) depicts a visual representation of relationships among variables. The procedure produces direct, indirect, and total effects represented by standardized coefficients. (Callaghan et al., 2018; Stage et al., 2004). We used the SPSS AMOS 26 software to test the hypothesized path model to

Table 4 Data description

Variable	Full score
Teacher self-efficacy	55
Teacher outcome expectancy	45
STEM attitudes	130
21^{st} century skills (learning confidence)	55
STEM career awareness	48
STEM knowledge achievement	20

Note: The data were deidentified using Student ID code. There is no missing value in the data investigate causal relationships between factors that could affect student learning in STEM. The path model was developed based on expectancy-value theory and previous research.

Results

Table 5 shows the descriptive statistics of the data, and Table 6 displays correlations between the variables. Fig. 2 depicts the relationships among the factors that affect student knowledge achievement directly and indirectly in integrated STEM learning.

The test of the path model showed that the model was overall acceptable: $\chi 2$ (1) = 23.225, $p < .001$; Comparative Fit Index (CFI) = .940; Incremental Fit Index (IFI) = .942 ; Tucker-Lewis index (TLI) = .70; Root Mean Square Error of Approximation (RMSEA) = .115.

As Fig. 2 illustrates, teacher self-efficacy and outcome expectancy directly and indirectly affects student STEM knowledge achievement. The standardized direct effect of teacher self-efficacy on student STEM knowledge was .159 ($p < .001$). The standardized indirect effect of teacher self-efficacy and teacher outcome expectancy on student STEM knowledge achievement was .035 ($p = .009$) and .044 ($p = .002$), respectively. Additionally, student STEM attitudes showed direct effects on student knowledge achievement ($B = .279$, $p < .001$) while student 21st century skills ($B = .093$, $p = .002$) and STEM career awareness ($B = .125$, $p = .003$) influenced STEM knowledge achievement indirectly when mediated by STEM attitudes. All significant direct and indirect effects were indicated in Table 7.

Note: Standardized estimates. Solid line path coefficients are significant at $p < .05$ while the dotted line path coefficients are nonsignificant

Summary

The study investigated how multiple factors of both students and teachers influence students' STEM learning with the two guiding questions as the following.

Table 5 Descriptive statistics of the data

	N	Min	Max	Mean		*SD*	Skewness		Kurtosis	
		Statistic	Statistic	Statistic	*SE*	Statistic	Statistic	*SE*	Statistic	*SE*
STEM knowledge	507	4	18	10.61	.151	3.408	.005	.108	−.851	.217
STEM attitudes	507	32	130	89.35	.715	16.097	.031	108	.344	.217
21st century skills	507	11	55	44.39	.296	6.659	−.731	.108	1.674	.217
STEM career awareness	507	12	48	27.59	.277	6.241	−.254	.108	−.034	.217
Teacher self-efficacy	507	31	55	47.41	.216	4.868	−.866	.108	−.838	.217
Teacher outcome expectancy	507	25	41	31.94	.167	3.761	−.032	.108	1.806	.217

Note: *Min*, minimum, *Max*, maximum, *SD*, standard deviation, *SE*, standard error

Table 6 Correlation coefficients among the variables (N = 507)

`	1	2	3	4	5	6
1. Student STEM knowledge	1.000					
2. Student STEM attitudes	.315**	1.000				
3. Student 21st century skills	.128**	.419**	1.000			
4. Student STEM career awareness	.168**	.512**	.210**	1.000		
5. Teacher self-efficacy	.200**	.132**	.000	.129**	.1.000	
6. Teacher outcome expectancy	.101*	.163**	.037	.013	.076	1.000

Note: *p < .05, **p < .01 (2-tailed).

1. Are teacher self-efficacy and outcome expectancy, student STEM attitudes, 21st century skills, and STEM career awareness positively associated with student STEM knowledge achievement?
2. Are there any direct and indirect effects of teacher self-efficacy and outcome expectancy on students' STEM attitudes, 21st century skills, and STEM career awareness?

For the first research question, the results reveal significant direct effects of teacher self-efficacy on students' STEM knowledge achievement (B = .159, p < .001). Student STEM attitudes also significantly influenced student STEM knowledge achievement (B = .279, p < .001). Even though no significant direct effects of teacher outcome expectancy on student STEM knowledge achievement were found, it indirectly influenced student achievement by affecting their STEM attitudes. Additionally, indirect effects of 21st century skills (.093) and STEM career awareness (.125) on STEM knowledge achievement were found to be significant when mediated by STEM attitudes.

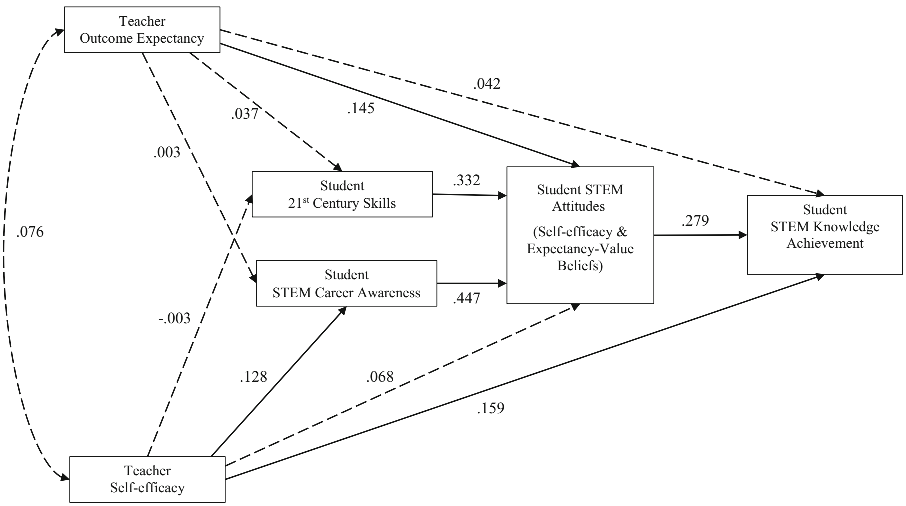

Fig. 2 Path model of integrated STEM learning.

Table 7 Standardized direct, indirect, and total effects in the SEM model

Predictor	Criterion	Direct effect	Indirect effect	Total effect
Teacher self-efficacy	Student STEM knowledge	.159**	.035**	.194**
Teacher self-efficacy	Student 21st century skills	−.003		−.003
Teacher self-efficacy	Student STEM attitudes	.068	.056*	.124*
Teacher self-efficacy	Student STEM career awareness	.128**		.128**
Teacher outcome-expectancy	Student STEM knowledge	.042	.044**	.086**
Teacher outcome-expectancy	Student 21st century skills	.037		.037
Teacher outcome-expectancy	Student STEM attitudes	.145**	.014	.159**
Teacher outcome-expectancy	Student STEM career awareness	.003		.003
Student STEM attitudes	Student STEM knowledge	.279**		.279**
Student 21st century skills	Student STEM knowledge		.093**	.093**
Student 21st century skills	Student STEM attitudes	.332**		.332**
Student STEM career awareness	Student STEM knowledge		.125**	.125**
Student STEM career awareness	Student STEM attitudes	.447**		.447**

Note: *$p < .05$, **$p < .01$ (two-tailed). Bootstrap approximation obtained by constructing two-sided bias-corrected confidence intervals

For the second research question, teacher outcome expectancy show significant direct effect on student STEM attitudes ($B = .145$, $p < .001$). Teacher self-efficacy show significant direct effect on student STEM career awareness ($B = .128$, $p < .001$) and indirect effect on STEM attitudes (.056). Both teacher self-efficacy and outcome expectancy did not show significant effects on student 21st century skills.

The findings of this study indicate that self-efficacy and expectancy-value beliefs are critical for both teachers and students in teaching and learning integrated STEM. The standardized path diagram depicts the collective effects of teacher factors and student factors on student STEM attitudes and knowledge achievement (See Fig. 2 and Table 7).

Discussion

Aiming to identity the factors that influence students' learning in STEM, the current study investigated the relationships among teacher self-efficacy and outcome expectancy, student STEM attitudes (self-efficacy and expectancy-value beliefs), 21st century skills, and STEM career awareness in an integrated STEM education context. According to the findings, the current study reinforces previous literature that teachers' self-efficacy and expectancy beliefs are critical factors for enhancing students' attitudes and performance, which sheds light on the importance of the teachers' roles in student learning.

Integrating different subjects into one project is a relatively new way of teaching and learning. Consequently, the effect of teachers self-efficacy and student attitudes (self-efficacy and expectancy-value beliefs) on students' achievement in an integrated

STEM context was not researched as much as that of in general classrooms. The findings of the current study are consistent with the previous literature, which found that teachers' beliefs in their teaching efficacy and success are strong predictors of students' self-efficacy, motivation, and academic performance (Cannon & Scharmann, 1996; Muijs & Reynolds, 2015; Podell & Soodak, 1993; Ross, 1992; Ross et al., 2001; Rutherford et al., 2017; Shahzad & Naureen, 2017; Tschannen-Moran & Barr, 2004; Yoon et al., 2012). This result indicates the significance of educating teachers since teacher self-efficacy for successful teaching relates to content knowledge, quality pedagogy, and teaching strategies considerably (Knowles, 2017, p. 25; Rutherford et al., 2017; Stohlmann et al., 2012; Yoon et al., 2012). Through professional development, teachers can construct a community of practice, where they could enhance knowledge, instructional skills, and pedagogical approaches (Kelley et al., 2020; Knowles et al., 2018).

Additionally, the present study draws attention to the importance of affective domains in STEM education (ITEEA, 2020; NGSS Lead States, 2013). Affective domain includes attitudes, interest, motivation, social skills, and so on, and researchers and instructional developers have been claimed to include affective domain in curriculum and instruction. However, the way of placing an affective domain within a curriculum can be different depending on the context, and many teachers lack attention to an affective domain (Hansen, 2009; Reigeluth, 1999). Therefore, teacher training programs that prepare teachers to teach students affective skills are recommended. For example, project-based instructions help students develop social and interpersonal skills (Hansen, 2009; Li et al., 2019). By learning how to incorporate project-based instruction in their teaching, teachers can enhance students' attitudes, self-efficacy beliefs, and motivation to learn (Abdullah et al., 2010; Markham, 2011; Mataka & Kowalske, 2015),

To teach integrated STEM, further research is needed to develop instructional strategies which are "focusing teaching and learning across all three domains of learning: cognitive, affective, and psychomotor" (ITEEA, 2020, p. 4; Griffith & Nguyen, 2006). Since integrated STEM education involves complex teaching strategies and requires insights into students' educational and psychological needs, which are different from general education, further discussions based on more empirical research are required.

Implication

The current study provides some theoretical and practical implications. First, the present study contributes to the research in expectancy-value theory framework with empirical evidence. Consistent with previous studies, the current study demonstrates that self-efficacy and outcome expectancy of both teachers and students are significant predictors of student STEM knowledge achievement as a direct factor or a mediator (Bradley et al., 1999; Caraway et al., 2003; Nadelson et al., 2012; Nugentet et al., 2015; Ross, 1992; Tschannen-Moran & Barr, 2004; Pajares & Miller, 1994; Yoon et al., 2012; Wood & Locke, 1987; Zimmerman et al., 1992). As noted earlier, teachers' self-efficacy and beliefs can influence the successful outcome of students' performance (Bal-Taştan et al., 2018; Borko & Whitcomb, 2008; Gulistan & Hussain, 2017; Perera

& John, 2020; Salgado et al., 2018), and students with strong competencies of success and efficacy beliefs tend to perform more challenging tasks and succeed more frequently (Bandura, 1994; Eccles & Wigfield, 2002). This finding confirms expectancy-value theory that expectations and task-value beliefs are linked to the achievement-related choice and performance of individuals (Eccles & Wigfield, 2002).

Second, this study indicates that students' STEM knowledge achievement is influenced not only by a single factor but also by multiple factors of both teachers and students. Although many studies have investigated the relationships between students' self-efficacy, motivation, and learning outcomes, few studies were reported on the multiple factors influencing student learning in STEM (Wiebe et al., 2018). Therefore, this study may provide implications by adding empirical evidence to the prior research. Specifically, as the path model illustrates, teacher self-efficacy and outcome expectancy are linked to student achievement directly or indirectly through student career interests and attitudes. Moreover, students' 21st century learning confidence and interests in future STEM careers significantly influenced their attitudes toward STEM, which in turn affected their academic achievement in STEM. Even though no significant direct effects of students' STEM career awareness and 21st century skills on their STEM knowledge achievement were found, indirect effects of STEM career awareness and 21st century skills mediated by STEM attitudes (student self-efficacy and outcome expectancy) were detected. These results imply that multiple factors interplay and finally affect student STEM knowledge achievement collectively.

Finally, the present study focused on all core STEM disciplines: science, technology, engineering, and mathematics. As prior studies of the relationship between motivation and achievement have been conducted mostly on science or mathematics alone, the present study addresses the gap in this area by using the S-STEM survey focusing on student attitudes (expectancy-value beliefs) toward all STEM subjects (Wiebe et al., 2018).

Limitation

This study has some limitations. Although construct validities of the instruments were confirmed, the respondents' honesty, which is required for self-report surveys, cannot be verified. Additionally, as the current study investigated the relationships between the factors of both teachers and students, teacher career awareness and 21st confidence may also need to be considered to draw conclusions that better discuss the findings. Finally, the variables of student STEM attitudes include both self-efficacy and expectancy-value beliefs while teacher variables include teacher self-efficacy and outcome expectancy separately. Following the instrument developers and previous studies, we used *STEM attitudes*, which indicate "a composite of both self-efficacy and expectancy-value beliefs" (Unfried et al., 2015, p. 23; Wiebe et al., 2018). This may not fully explain the effect of each specific factor, self-efficacy and expectancy-value beliefs.

Appendix 1

D-BAIT STEM knowledge test item analysis results

Item no	Difficulty		Discrimination		Cronbach's alpha if item deleted
	Score	Index	Score	Index	
1	0.67	Easy	0.44	Very good	0.68
2	0.58	Moderate	0.42	Very good	0.69
3	0.14	Very difficult*	−0.06	Poor**	0.71
4	0.10	Very difficult*	0.03	Poor**	0.70
5	0.44	Moderate	0.45	Very good	0.68
6	0.32	Difficult	0.31	Good	0.69
7	0.42	Moderate	0.42	Very good	0.69
8	0.45	Moderate	0.54	Very good	0.68
9	0.78	Easy	0.38	Good	0.68
10	0.44	Moderate	0.50	Very good	0.68
11	0.42	Moderate	0.55	Very good	0.68
12	0.51	Moderate	0.40	Good	0.69
13	0.53	Moderate	0.59	Very good	0.67
14	0.51	Moderate	0.29	Marginal	0.70
15	0.52	Moderate	0.50	Very good	0.68
16	0.25	Difficult	0.42	Very good	0.68
17	0.51	Moderate	0.41	Very good	0.69
18	0.58	Moderate	0.52	Very good	0.68
19	0.46	Moderate	0.28	Marginal	0.70
20	0.53	Moderate	0.62	Very good	0.67
21	0.29	Difficult	0.42	Very good	0.68
22	0.53	Moderate	0.47	Very good	0.68
23	0.33	Difficult	0.19	Poor**	0.70
24	0.11	Very difficult*	−0.06	Poor**	0.71
Average	0.43	Moderate	0.38	Good	0.69

Note: Item 3, 4, 23, and 24 were removed as these showed low scores in difficulty and item discrimination

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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